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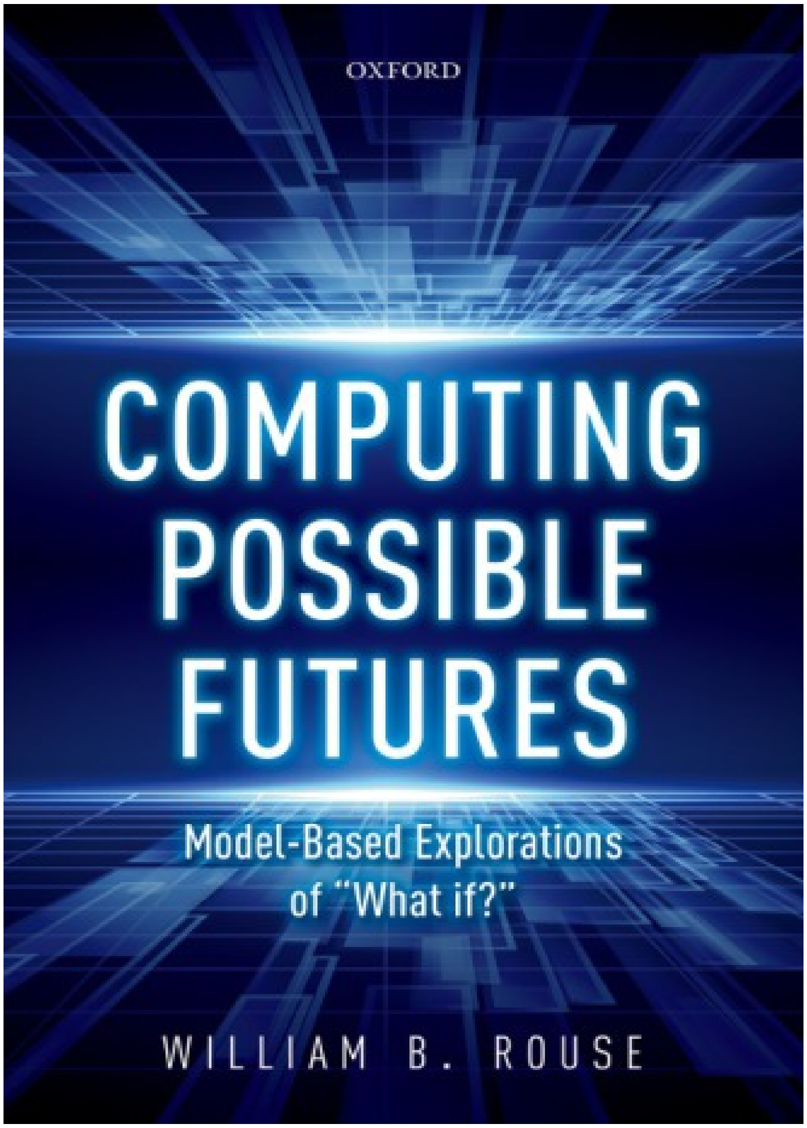

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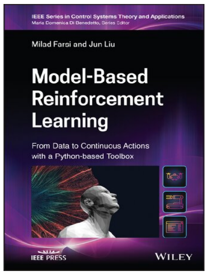

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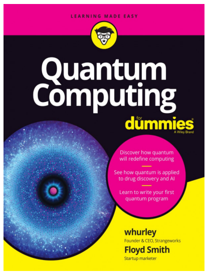

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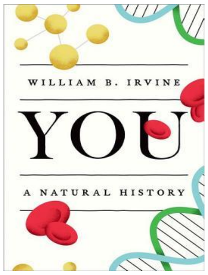

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COMPUTING POSSIBLE FUTURES

Model-Based Explorations of "What if?"

WILLIAM B. ROUSE

Computing Possible Futures

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PREFACE

I have worked with thousands of executives and senior managers during the nonacademic elements of my career, in over 100 enterprises. For the past decade, I have worked with executives of well over 10 large U.S. healthcare providers. They are very interested in what "data analytics" can do for them and, quite recently, what the prospects are for "AI and machine learning."

These executives were trained in science in medical school, where they were familiar with basic math, for example, algebra and statistics. But that was a long time ago. Nevertheless, they really want to understand these topics, their implications, and how they can best invest to take advantage of these trends. As a result, I spend more time explaining modeling to my consulting clients than to my students.

I have had similar experiences with executives in the automotive, aerospace, consumer, electronics, pharmaceutical, publishing, and semiconductor industries. They are well educated and highly motivated. They want to understand and then invest wisely. And—they are reasonably skeptical. They have often experienced overselling and under-delivery.

They ask about reasonable and realistic expectations. *Computing Possible Futures* addresses this question. Their concern is with the *futurity* of decisions they are currently entertaining. They cannot fully address this concern empirically. The future does not yet exist to be measured. Thus, they need some way to make predictions.

Various pundits, and perhaps a few oracles, will confidently tell them what to expect. Most executives want more rigor than this. Computational modeling can usually provide substantially more rigor than expert, or not so expert, opinion can. These models can be used to predict the future.

Executives want these predictions to be accurate. The problem is that we rarely can predict exactly what will happen, only what *might* happen. To overcome this limitation, executives can be provided predictions of possible futures and the conditions under which each scenario is likely to emerge. Models can help them to understand these *possible* futures.

I have found that most executives find such candor refreshing, perhaps even liberating. Their job becomes one of imagining and designing a portfolio of possible futures, assisted by interactive computational models. Understanding and managing uncertainty is central to their job. Indeed, doing this better than competitors is a hallmark of success.

Computing Possible Futures is intended to help them to understand what fundamentally needs to be done, why it needs to be done, and how to do it. Such readers are unlikely to be the ones who will create the computational models. These executives will recruit managers who will hire and guide the modelers. My hope is that all of these people will read and discuss *Computing Possible Futures*, developing a "shared mental model" in the process, which greatly enhances their chances of success.

Who else are intended readers of *Computing Possible Futures*? Those who want to sell modeling engagements to executives will find that this book helps them. Accenture, Bain, Boston Consulting Group, IBM, and McKinsey are among this group, collectively employing hundreds of thousands of consultants. *Computing Possible Futures* is intended to provide the "lingua franca" among the consumers and providers of computational modeling.

Computing Possible Futures is not a textbook. There is not enough theory and math for most faculty members. Students will, however, want to read this book to imagine working for companies that employ this approach to understanding and managing the complexities of their markets. They may want to imagine working for the above consulting companies. These students might be pursuing MBAs, but the engineer in me leads to my belief that this book will be more popular with aspiring and recently minted engineers.

Much of the material in *Computing Possible Futures* is case based, with stories of how I have used the models to support executives and senior managers to make well-informed decisions. Many people have told me that these stories are what bring model-based decision-making to life. My sense is that interesting and insightful stories are the best way to communicate and provide readers motivations to dig deeper.

Scores of people have influenced my thinking in this arena and contributed to the stories that I relate. With over 50 years of experiences, acknowledging

everyone who has played a part would consume too much space. I would easily be at risk of forgetting people who played important roles. Thus, I will keep this simple. Thank you.

William B. Rouse
Washington, DC
January 2019

CONTENTS

CHAPTER 1

Introduction

There are many "what is?" questions. What is the temperature outside? How many people are in line at customer service? What is the shortest route from A to B? How many people graduated from high school last year? With the right data, including your own observations, these questions can readily be answered.

"What if?" questions are different. They cannot be answered empirically because the future you are considering does not yet exist. How long would it take if we walked instead of drove? How many people will graduate over the next decade? What if we moved our investments from X to Y?

Addressing these types of question requires predictions. Sometimes these predictions come from our mental models of the phenomena of interest. For example, we may know the streets of the city pretty well and have experienced past traffic patterns. We use this knowledge to imagine the time required.

We might extrapolate to answer the question. We know the number of children alive at the right ages to graduate over the next decade. We can access actuarial tables on mortality to predict how many will make it to high school. We don't know what will happen economically or socially over the next decade, so we expect the predictions we calculate will have some associated uncertainty.

The notion of our predictions being uncertain is central to the discussions in this book. We cannot know what *will* happen, but we can predict what *might* happen. Further, a range of futures might happen. This range will include *possible futures*. Many futures will be very unlikely. That is useful to know as well.

How can you project the possible futures relative to the "what if?" question of interest? Beyond using your mental models and your imagination, you can

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employ computational models. These exist in a variety of forms, ranging from quite simple to very sophisticated.

The simplest form is proverbial "back of the envelope" estimates, which, in my experience, are more often on tablecloths or cocktail napkins than envelopes. I often try to estimate the answers I expect from computational models. Using simplifications that make calculations easier, I derive a very rough estimate of what I expect. If my estimate differs significantly from what the computational model provides, I track down the source(s) of the discrepancy.

From this traditional first step, you might next formulate a set of mathematical equations. This usually starts with paper and pen and perhaps results in a spreadsheet model. This can provide more precise predictions and, hopefully, more accurate predictions. Of course, this by no means eliminates the uncertainties noted above.

The next formulation may transition the spreadsheet model to a computer program that enables including uncertainties and provides a variety of visual representations of predictions. This may involve using one or more commercially available software tools, several of which are noted in later chapters.

Simple Examples

This section uses some simple examples to illustrate the issues raised above. My goal is to set the stage for less simple examples later in this chapter, as well as much more elaborate stories in later chapters.

Waiting in Line

Figure 1.1 portrays a classic waiting line. Customers are concerned with how long they will have to wait to be serviced. We want to predict this for them.

We can use queuing theory to model this waiting line. Assume that customers arrive randomly at an average rate of λ customers per hour and are serviced at an average rate of μ per hour. The utilization of this queuing system, ρ, is defined as the ratio λ/μ. The mean number of people in the system, L, including the person being served, equals $\rho/(1 - \rho)$. The standard deviation is the square root of $\rho/(1 - \rho)^2$.

It is clear that $\rho < 1$. Otherwise, L becomes infinite, because the server can never catch up with the number of people waiting. If $\rho = 0.9$, then L equals 9, and the standard deviation of the number of people waiting is, roughly, 9 as

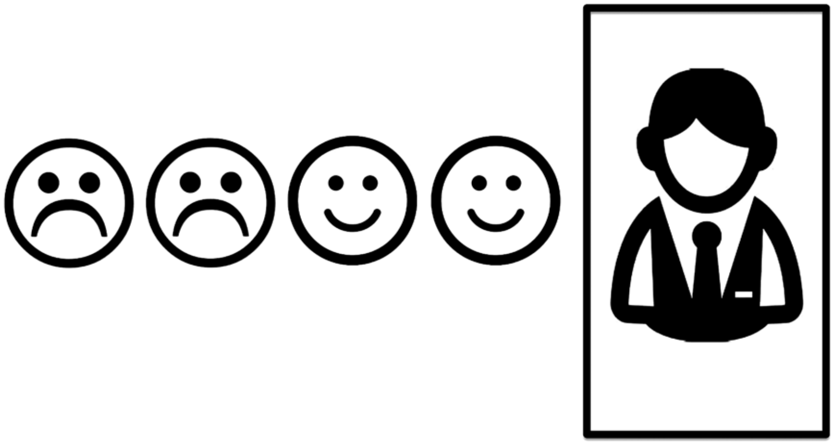

Fig 1.1 Waiting in line.

well. The answer to the customer's question is that there will, on average, be 8–9 people ahead of them, but sometimes it will be many more. With $\rho = 0.9$, there will often be significant waiting time. So, the possible futures for customers are quite varied.

This is a standard and quite simple queuing model. A few key aspects of the real problem are missing. Customers, upon seeing the waiting line, may "balk" and not enter the line. Other customers may wait a bit but then "renege" and leave the waiting line. Both of those behaviors will benefit those who remain in line, but they may not help the service organization's reputation. To avoid this, the organization may add a second server, which would require a significant expansion of this model.

In this example, we have portrayed the range of possible futures in terms of a mean and a standard deviation. Any "point" prediction, for example, predicting exactly nine people in the system, would almost always be wrong. This is due to random variations of interarrival and service times, as well as the simplicity of the model, for example, no balking or reneging. Nevertheless, such a model could be a reasonable first step. It at least tells that we need more than one server, or a spacious waiting room.

Investing for Retirement

This is a problem almost everybody eventually faces. You need money for your living expenses, which are denoted by LE. Due to inflation, at an annual rate of

α, this amount increases with years. In anticipation of retirement, every year you invest money, which is denoted by RI, and earn investment returns at an annual rate of β. Over time, these retirement assets, denoted RA, steadily grow.

Assume you do this for 20 years and then retire. At this point, you draw from RA to pay for LE, no longer investing RI each year. What should RI equal during the years that you are still working and investing?

Figure 1.2 portrays the results when α is 3 %, β is 7 %, LE equals \$100,000, and RI equals \$50,000, assuming that the latter amount is held constant over the working years. Exponential growth of your assets during the first 20 years is replaced by accelerating decline of, starting in Year 21. The acceleration is due to the fact that your living expenses are steadily increasing because of the 3 % inflation, from \$100,000 in Year 1 to \$317,000 in Year 40. Despite the ongoing 7 % return on your remaining assets, your living expenses drain these assets. In contrast, if inflation were 0 %, your assets would steadily increase over the 40 years, leaving your heirs with a tidy inheritance. Alternatively, you could decrease your annual investment to \$26,000 to break even in Year 40.

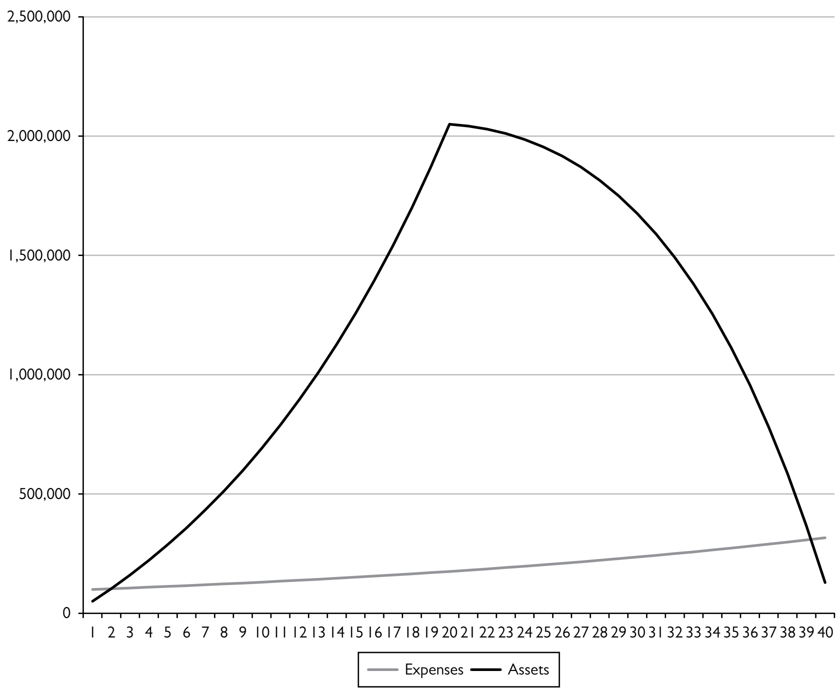

Fig 1.2 Expenses and assets over 40 years.

This seems like a fairly straightforward model, not unlike those embedded in many retirement planning applications on the Internet. However, it only provides point predictions for a process with substantial volatility. Inflation rates and investment return rates are highly variable.

Thus, the projections shown in Figure 1.2 look much more certain than they are in reality. Of course, one can update such projections each year and, if fortunate, adjust investments for any surprises. However, starting in Year 21, you have no more working income to use to compensate for these surprises. This seems to have caused many people to put off retirement.

This model is useful in that it illustrates the enormous impact of even modest inflation compounded over 40 years. Yet, it does not portray the different scenarios that might play out. We could vary α and β to determine the RI needed for each combination. This would constitute an elementary form of "scenario planning," a topic addressed in Chapter 3.

Driving a Vehicle

We would like to predict the performance of a vehicle, for example, time to accelerate from 0 to 60 miles per hour, and stability on curves, as a function of the design of the vehicle. This requires that we predict driver performance in the manual control of the vehicle. This prediction problem is addressed in depth in Chapter 6, but is simplified here.

The block diagram in Figure 1.3 represents the driver–vehicle system. Using a model based on this figure, we can predict the performance of this system. These predictions would likely be reasonably accurate for drivers maintaining lane position and speed on straight roads in clear weather in daylight. However, reality includes irregular roads, wind, rain—and other drivers!

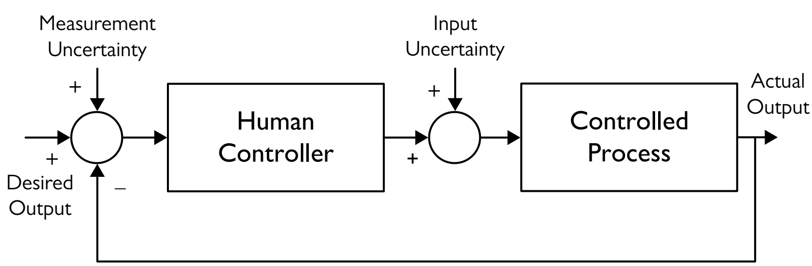

Fig 1.3 Driver–vehicle system.

This model includes a desired output—the intended path—measurement uncertainty representing possible limited visibility, and input uncertainty representing driver variability in steering, accelerating, and braking. This model should yield reasonable predictions, but it does not include important factors like traffic flow, other drivers' behaviors, and possible distractions, for example, fussing with the entertainment system. Many sources of uncertainty and variability are missing. Nevertheless, this model would be useful for predicting driver–vehicle performance in, admittedly, pristine conditions.

This is a good example of a model that might be used to diagnose poor designs but is not sufficient to fully validate good designs. It is common for such validation to happen in human-in-the-loop driving simulators that combine computational models of the vehicle with live human drivers in simulated realistic driving conditions.

Less Simple Examples

At this point, I move from hypothetical examples, which were created to illustrate key points, to real models developed to help decision-makers answer questions of importance. Nevertheless, the depth with which these two examples are discussed is limited to that necessary to further elaborate the issues raised in this chapter.

Provisioning Submarines with Spare Parts

My first engineering assignment when I worked at Raytheon was to determine the mix of spare parts that a submarine should carry to maximize the system availability of the sonar system. Availability is the probability that a system will perform as required during a mission, which, for a submarine, could be months.

System availability is affected by failure rates of component parts, repair times for failures, and relationships among components. Functional dependencies and redundancies affect the extent to which a failed part disables the overall system. Redundant parts provide backups to failures. Figure 1.4 depicts a notional sonar system.

The simulation model developed was called MOSES, for Mission Oriented System Effectiveness Synthesis (Rouse, 1969). MOSES included a representation of the system similar to Figure 1.4. Data for the thousands of parts in the

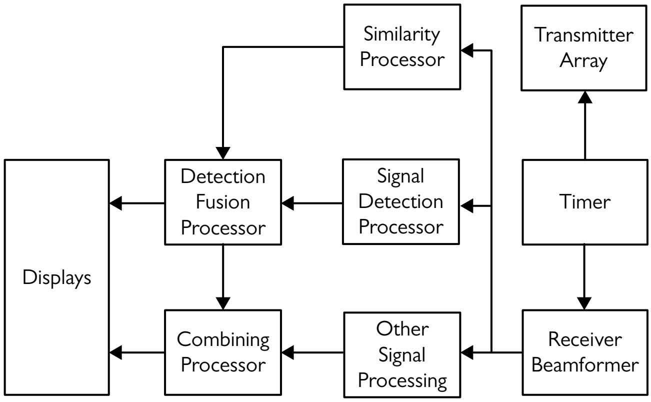

Fig 1.4 Notional sonar system.

system, obtained from contractually required testing, included the mean time between failures (MTBF) and the mean time to repair (MTTR) for each part.

MOSES simulated operation of the sonar system over long missions such as, for example, a 30-day mission. As failures occurred, the structure of the system (Figure 1.4) was used to determine the impact on system operations, that is, whether or not the system was available. Maintenance actions were also simulated, solely in terms of time required to replace the failed part. Across the whole simulation of the mission and system operations, the overall availability statistic equaled MTBF/(MTBF + MTTR).

Typically, the MTBF is much larger than the MTTR. Otherwise, availability suffers. On the other hand, if repairs are instantaneous, that is, MTTR equals zero, availability is 100 %, regardless of the MTBF. This might seem extreme, but redundant parts that are automatically switched into use are increasingly common.

Determining the best mix of spare parts involved finding the mix that maximized availability within the physical space constraints of the submarine. MOSES was also used to determine where increased redundancy would most improve availability. The number of requests for various MOSES analyses resulted in many long simulation runs, which led the personnel in the computer center to comment that MOSES was often wandering in wilderness.

This example involved a complicated system of which we had ample knowledge because all of it was designed or engineered. There were no humans interacting with the system. MOSES did not consider whether the targets and threats detected by the sonar system were successfully engaged. In other words, the

Exploring the Variety of Random Documents with Different Content

TO SOMEBODY

HAROLD SETON

in Munsey's Magazine

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THEY've put us through our paces;
They say we're doing fine;
We'll soon go to our places
Upon the firing-line.
Some chaps will fight for mothers,
And some for wives so true;
For sweethearts many others,
And I will fight for you!

Through all these months of training
We've cherished hopeful thoughts
And drilled without complaining,
Like soldiers and good sports.
We're warring for a reason,
We've sworn to see this through;
To falter would be treason,
And I will fight for you!

Your presence will be near me,
Your voice will call my name;
You'll comfort me and cheer me,
Your love, behold, I claim!
'Twould take more than an ocean
To separate us two;
I'll hold unto this notion,
And I will fight for you!

WAR

COL. WILLIAM LIGHTFOOT VISSCHER

IN THE SCOOP, THE CHICAGO PRESS CLUB'S MAGAZINE

BY blazing homes, through forests torn
And blackened harvest fields,
The grim and drunken god of war
  In frenzied fury reels.

His breath—the sulph'rous stench of guns—
  That death and famine deals
And Pity, pleading, wounded falls
  Beneath his steel-shod heels.

A MARCHING SOLILOQUY

BY A MEMBER OF THE S. A. T. C., NORTHWESTERN COLLEGE, NAPERVILLE, ILL.

"Left!
Left!"
Had a good girl when I
"Left!
Left!"
Mighty good pal when I
"Left!"
"One! Two! Three! Four!"
How
many
miles
more?
"Left!

"Left!
Left!"
Booked for a wife when I
"Left!
Left!"
That was my life when I
"Left!"
"One! Two! Three! Four!"
Hear
old
Lieutenant
roar
"Left!"

WHILE SUMMERS PASS

ALINE MICHAELIS

in The Enterprise, Beaumont, Texas

SUMMER comes and summer goes,
Buds the primrose, fades the rose;
  But his footfall on the grass,
Coming swiftly to my door,
I shall hear again no more,
  Though a thousand summers pass.

Once he loved the clovers well,
Loved the larkspur and bluebell.
  And the scent the plum-blooms yield;
But strange flowers his soul beguiled,
Pallid lilies, laurels wild,
  Blooming in a crimson field.

So he plucked the laurels there,
And he found them sweet and fair
  In that field of blood-red hue;
And, when on a summer night
Moonlight drenched my clovers white,
  Lo! He plucked Death's lilies, too.

It may be that e'en to-night,
In the Gardens of Delight,
  Where his shining soul must dwell,
He has found some flowers more sweet
Than the clovers at my feet,
  Some celestial asphodel.

But while summer comes and goes,
With the primrose and the rose
  Comes his footfall on the grass—
Gladly, lightly to my door—
I shall hear it echo o'er,
  Though a thousand summers pass.

THE MARINES

ADOLPHE E. SMYLIE

OF THE VIGILANTES

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"PARDON! he has no Engleesh, heem,
Il ne parle que Française,
I spik it leetle some Monsieur,
Vaire bad, j'en suis fâché—
Marines? Mais oui! I fight wiz zem
At Château Thierry
An' on ze Ourcq an' Marne in grand
Bon camaraderie.
I see zem fight at bois Belleau,
Like sauvage make ze yell,—
Sacre nom de Dieu! zoze sailor man
Eez fightin' like ze hell!
All time zey smile when make ze push,
Magnifique zaire élan,
Zey show ze heart of lion
For delight our brav Franchman.
An' in ze tranch at rest, zoze troop
From ze Etats Unis
Queeck make ze good frien' of poilu
Wiz beeg slap on ze knee!
Zey make ze song an' joke, si drôle
An' pass ze cigarette;
Zey call us goddam good ol' scout
Like Marquis La Fayette.
Next day, mebbee, again ze taps—
Ze volley in ze air.—
Adieu! some fightin' sailor man
Eez gone West. C'est la guerre!
No more ze smile, ze hug, ze hand
Queeck wiz ze cigarette;
C'est vrai, at funerall of *heem*
Ze poilu's eye eez wet.
But, every day like tidal wave,—
Like human avalanche,—
Ze transport bring more Yankee troop,

To get ze beeg revanche!
Zen from ze heart Américaine
Come milliards of monnaie;
Eet eez ze end! Your country bring
Triomphant liberté.
So, au revoir! I mus’ go on
But first I tell to you
What some high Officier remark
Zat day at bois Belleau.
He says, our great Napoleon
Wiz envy would turn green
Eef he could see zoze sailor man,—
Zoze Uncle Sam Marines!”

AN AMBULANCE DRIVER'S PRAYER

LIEUT. CHAPLAIN THOMAS F. COAKLEY

IN THE STARS AND STRIPES, A.E.F., FRANCE

'Mid blinding rain this inky night,
Loud bursting shells each foot of road,
Thy Light, O Christ, will guide me right,
To save this gasping, dying load.

Their shattered limbs have followed Thee;
Their wounded hands have done Thy work.
They bled, O Lord, to make men free;
They fought the fight—they did not shirk.

NOT TOO OLD TO FIGHT

T. C. HARBAUGH

IN THE CHICAGO LEDGER

MY name is Danny Bloomer and my age is eighty-three,
Years ago I went with Sherman to the ever sunny sea.
I stood my ground at Gettysburg, that bloody summer day,
When gallant Pickett rushed the hill and lost his boys in gray;
And now our starry banner is insulted and defied,
The kaiser tears it into shreds and glories in his pride;
Just pass the word across the sea to his stronghold of might,
And say that Danny Bloomer's here and not too old to fight.

I gave my youth to Uncle Sam in years I'll ne'er forget,
In mem'ry of those stirring times my old blood tingles yet.
With four score years upon me I can lift the same old gun,
And to face our Flag's insulter will be everlasting fun.
Please say that Danny Bloomer is ready for the fray,
Cry "Forward, march!" and see him in the good old ranks today.
I love the flag of Washington because it stands for Right,
And that is why I tell you I am not too old to fight.

'Tis true I'm somewhat crippled, but I do not care for that,
I feel as young as when I saw the tilt of Sherman's hat;
I want to do my duty again before I die,
And see Old Glory proudly in the streets of Berlin fly.
I do not know the kaiser, but I hope within a year
Amid the roar of cannon he will say, "Old Bloomer's here!"
Yes, hand me down a rifle and I will use it right,
Your Uncle Danny Bloomer isn't yet too old to fight.
We've borne their insults long enough—they make me long to go.
I want to squint along my gun and aim it at the foe;
I'll eat the same old rations that I ate in '64,
And feel the blood of youth again amid the battle's roar.
I haven't long to tarry here until my work is done,
But I want to show the kaiser we're not in it for fun;
So give me marching orders and I'll disappear from sight,
For I am Danny Bloomer, and I'm not too old to fight.

A WAYSIDE IN FRANCE

ADOLPHE E. SMYLIE

in The New York Herald

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“COME shake hands, my little peach blossom.
That’s right, dear, climb up on my knee.
This big Yankee soldier is lonesome—
Ah, now we’ll be friends, ma chérie.
We won’t understand one another,
Your round eyes are telling me so,
But the cling of your chubby fingers
Is a language that all daddies know.
When I caught a sight of your pigtails
And those eyes of violet blue,
It made me heart-hungry, ma petite,
For I’ve a wee girl just like you.
She lives ’way across the wide ocean,
Out where the bald eagles nest,
And she knows all the chipmunks and gophers
At my shack out in the West.”

“Tu dis l’ouest! Est-ce ton pays?
Veux-tu, quand tu iras chez-toi—
Maman est toujours à pleurer—
Me retrouver mon soldat Papa?
Il etait avec sa batterie
Près des Anglais la, en campagne,
Mais Papa est allé dans l’ouest,
Des Anglais disaient à Maman.
Alors, Maman sera heureuse
Et, tu vois elle ne pleurera plus;
Je veux te donner un baiser,—
Merci! Tu es si bon pour nous!”

There she goes! She told me her secret,
Kissed me and then flew away,—
Say, Poilu! You savez some English,
Now what did that little tot say?
“She say Engleeshman tol’ her Mama
Zat her soldat Papa eez gone West!

Zat her soldat Papa eez gone West!
You said West, bien! Zen you live zaire,
So she make you her leetle request,
Zat you find heem in your countree
So her Mama no more she weel cry;
Zen she thank you an' kees you, si joyeuse,—
Pauvre mignonne, she think you weel try!"

MISSING

"IRIS"

FROM B. L. T.'S COLUMN IN THE CHICAGO TRIBUNE

THE soldier boys are marching, are marching past my door;
They're off to fight for Freedom, to wage and win the war;
And yet I cannot cheer them, my eyes are full of tears—
My son, who should be with them, is dead these many years.

I've missed his boyish laughter, I've missed his sunny ways,
I've lived alone with sorrow through endless empty days.
But now my bitter longing dims all the grief before—
His boyhood friends are marching, without him, past my door.

I've envied happy mothers the children at their knee;
Their very joys seemed given to mock my grief and me.
Time healed those wounds, but this one will pain me while I live—
When Freedom called her warriors, I had no son to give.

And still the boys are marching, are marching toward the sea,
To suffer and to conquer, that all men may be free.
Be glad for them, O mothers! and leave to me the tears—
My son, who should be with them, is dead these many years.

THE RIVERS OF FRANCE

H. J. M.

IN THE ENGLISH REVIEW

THE rivers of France are ten score and twain,
But five are the names that we know—
The Marne, the Vesle, the Ourcq, and the Aisne,
And the Somme of the swampy flow.

The rivers of France, from source to the sea,
Are nourished by many a rill,
But these five, if ever a drought there be,
The fountains of sorrow would fill.

The rivers of France shine silvery white,
But the waters of five are red
With the richest blood, in the fiercest fight
For Freedom, that ever was shed.

The rivers of France sing soft as they run,
But five have a song of their own,
That hymns the fall of the arrogant one
And the proud cast down from his throne.

The rivers of France all quietly take
To sleep in the house of their birth,
But the carnadined wave of five shall break
On the uttermost strands of Earth.

Five rivers of France, see their names are writ
On a banner of crimson and gold,
And the glory of those who fashioned it
Shall nevermore cease to be told.

JUST THINKING

HUDSON HAWLEY

IN THE STARS AND STRIPES, A. E. F., FRANCE

STANDIN' up here on the fire-step,
Lookin' ahead in the mist,
With a tin hat over your ivory
   And a rifle clutched in your fist;
Waitin' and watchin' and wond'rin'
   If the Hun's comin' over tonight—
Say, aren't the things you think of
   Enough to give you a fright?

Things you ain't even thought of
   For a couple o' months or more;
Things that 'ull set you laughin',
   Things that 'ull make you sore;
Things that you saw in the movies,
   Things that you saw on the street,
Things that you're really proud of
   Things that are—not so sweet;

Debts that are past collectin',
   Stories you hear and forget,
Ball games and birthday parties,
   Hours of drill in the wet;
Headlines, recruitin' posters,
   Sunset 'way out at sea,
Evenings of pay-days—golly—
   It's a queer thing, this memory!

Faces of pals in Homeburg,
   Voices of womenfolk,
Verses you learnt in schooldays
   Pop up in the mist and smoke
As you stand there grippin' that rifle,
   A-starin', and chilled to the bone,
Wonderin' and wonderin' and wonderin',
   Just thinkin' there—all alone:

When will the war be over?
    When will the gang break through?
What will the U. S. look like?
    What will there be to do?
Where will the Boches be then?
    Who will have married Nell?
When's the relief a-comin' up?—
    Gosh! But this thinkin's hell!

THE EVENING STAR

HAROLD SETON

IN THE CHICAGO EVENING POST

THE evening star a child espied,
The one star in the sky.
"Is that God's service flag?" he cried,
And waited for reply.

The mother paused a moment ere
She told the little one—
"Yes, that is why the star is there!
God gave His only Son!"

COLUMBIA'S PRAYER

THOMAS P. BASHAW

in The Herald and Examiner, Chicago

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